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THE RELATIVE BIOLOGICAL EFFECTIVENESS OF X-RAY, CO⁶⁰ GAMMA-RAY, AND 14.1 MEV FAST NEUTRON FOR ACUTE DEATH IN MICE

By

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マウスの急性死に対する X 線, Co⁶⁰ ガンマー線, 14.1 MeV

速中性子線の生物学的効果比

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ddN 均一系マウス (雌, 10週令) に 200 kVp X 線, Co⁶⁰ ガンマー線, 14.1 MeV 速中性子線を 1 回全身照射して, LD_{50/30} を指標とした生物学的効果比 (RBE) を求めた。

マウスの 30 日死亡率についての各放射線の

Probit 回帰直線 から, LD_{50/30} として, X 線は 640rad, ガンマー線は 870rad, 速中性子線は 560rad という結果が得られた。したがって, X 線の RBE を 1.0 とすると, ガンマー線のそれは 0.7, 速中性子線は 1.1 と算出された。

INTRODUCTION

Several reports have been published on the lethal effects of neutrons on experimental animals. However, the exact lethal neutron dose depends on physical factors, such as neutron energy (MeV) and dose rate, and biological factors of animals, such as species, strain, age and sex.

In the present study, LD_{50/30} was determined for mice exposed to single whole-body irradiation of 14.1 MeV fast neutron produced by T (d,n) reaction, and then the relative biological effectiveness (RBE) of this fast neutron and Co⁶⁰ gamma-ray versus 200 kVp X-ray was measured for lethal effect of irradiated mice.

MATERIAL AND METHODS

Animals In the present experiments, ddN female mice supplied by Central Laboratory for Experimental Animals (CLEA) were used. At the time of irradiation the age of mice was 10 weeks and their mean weight was 23±2 gm. The animals were maintained on CE-2-type pellets prepared by the foregoing Laboratory and water *ad libitum*.

X-ray irradiation The principal radiation factors were tube voltage: 200 kVp, HVL: 1.79 mm Cu, filter: 1.0 mm Cu + 0.5 mm Al, focus to center-of-mouse distance: 65 cm, and dose rate: 10 rad/min. X-ray dosage was determined in air with Radocon (Probe 601) manufactured by Victoreen Instrument Co.. The X-ray air dose in roentgen was converted to absorbed dose in rads by the factor of 0.95 rad/r. The mice were simultaneously irradiated in a plastic cage, 20×20×3 cm in size, in groups of 10 mice per cage.

Co⁶⁰ gamma-ray irradiation The Co⁶⁰ source used in the experiments was approximately 900 curies. Dose rate measurements were made in air with a Toshiba Model MI-102B radiation dosimeter and a ferric dosimeter. The distance from the center-of-mouse to the source was 110 cm, providing a dose rate of approximately 11 rad/min. Roentgen unit was converted to rad unit by multiplying by the factor of 0.97. Twenty mice were placed at a time in a plastic cage, 20×20×3 cm in size. During irradiation the cage was covered with a plastic plate of 5 mm in thickness to provide the maximum dose to the animals.

Fast neutron irradiation Neutron beam was obtained from the source generator by T (d,n) reaction. Fast neutrons produced in this reaction have a monochromatic energy of 14.1 MeV without being accompanied by gamma-ray contamination. Neutron dose was measured by means of activation method using ³²S (n,p) ³²P reaction and plastic scintillation method. The single-collision dose for 14.1 MeV fast neutron was computed to be 6.7×10^{-9} rad/n/cm² in soft tissue (refer to Randolph¹⁾ and Yamamoto *et al*²⁾). The method employed in neutron dosimetry has been described in detail by Yoshinaga and Antoku³⁾

Table 1. Mortality of ddN female mice after single exposure to 200 kVp X-ray, Co⁶⁰gamma-ray, and 14.1 MeV fast neutron

Dose (rad)	No. of mice	Deaths during 30-day post-irradiation	30-day mortality (per cent)
200 kVp X-ray			
720	30	24	80
700	10	6	60
690	30	28	93
660	20	10	50
650	10	2	20
630	30	16	53
600	40	17	42.5
550	20	6	30
500	20	0	0
	210	109	
Co⁶⁰ gamma-ray			
1000	20	20	100
950	20	18	90
940	20	15	75
910	20	12	60
14.1 MeV fast neutron			
900	20	15	75
880	20	14	70
850	40	13	32.5
820	20	6	30
800	20	5	25
	200	118	
650	20	19	95
620	30	14	47
600	20	19	95
590	30	9	30
560	30	7	23
550	20	12	60
530	30	7	23
500	50	12	24
450	20	2	10
400	20	0	0
	270	101	

of this Department.

The neutron generator was operated at accelerating voltage of 150 kV and beam current of about $300\mu\text{A}$. The distance from the center of target to the mid-point of the mouse was 5 cm at which distance the dose rate delivered was 4 to 11 rad/min. Plastic tubes used to house one mouse each during irradiation were arranged along a circular exposure rack, and 10 mice were irradiated at a time. Each mouse could freely move about in the tube, while the animal exposure rack was slowly revolved about the target to ensure uniform irradiation.

In order to eliminate the effect of dose rate dependency in each procedure, the three radiations were made to be identical as much as possible in their dose rate.

The data on the number of mice and radiation doses are summarized in Table 1.

RESULTS AND DISCUSSION

The 30-day mortality data for mice exposed to 200 kVp X-ray, Co^{60} gamma-ray and 14.1 MeV fast neutron are presented in Table 1. The probit regression lines for per cent

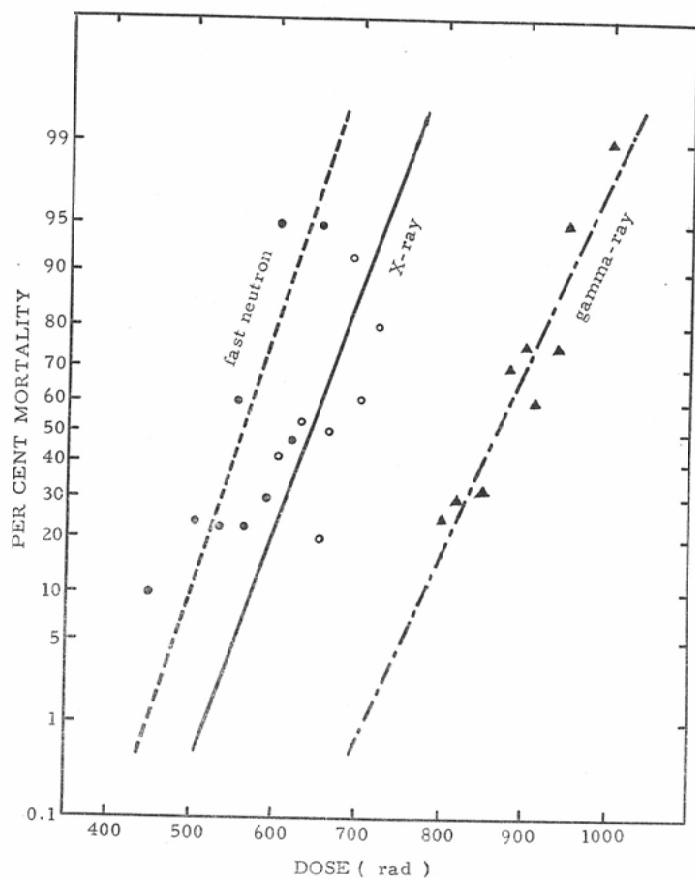


Fig. 1. Thirty-day mortality in *ddN* female mice exposed to 200 kVp X-ray, Co^{60} gamma-ray, and 14.1 MeV fast neutron.

mortality in mice irradiated at various doses of each of these three radiations are graphically shown in Fig. 1. From the mortality data for each radiation, it was determined that the $LD_{50/30}$ was 640 rad for X-ray, 870 rad for gamma-ray, and 560 rad for fast neutron. As shown in the data, however, the dose-response relationship in the neutron irradiated group is not well defined as compared with that in the X- or gamma-irradiated groups. Although the reason for this phenomenon in neutron irradiation is yet unknown at present, this may be related to the short target-to-mouse distance.

As the biological indicator for $LD_{50/30}$ values, if the RBE of 200 kVp X-ray is assumed to be 1.0, the RBE of Co^{60} gamma-ray would be 0.73 and that of 14.1 MeV fast neutron would be 1.14.

Since only a few studies have been made on the RBE of 14.1 MeV fast neutron for acute lethality in mice, it is difficult to make any comparison with the present results. The RBE value of approximately 1.1 obtained for $LD_{50/30}$ of mice in this experiment is considerably lower than the RBE of neutrons having higher LET.* However, Storer *et al*⁴⁾ have reported that the RBE of various ionizing radiations increases with elevation of LET. In view of this, it is very interesting that the RBE value obtained in this study has nearly the same value obtained by Riley *et al*⁵⁾ for neutrons (7- to 12-MeV range) having the energy almost equal to 14.1 MeV fast neutron. On the other hand, the RBE of Co^{60} gamma-ray is in good agreement with the values reported by many investigators.

In determining the RBE for neutrons, the most basic question is to make adequate neutron dosimetry. Yoshinaga and Antoku³⁾ have pointed out that with the neutron source used in the present experiment the change in dosimetric technique will affect the RBE value in some degree. However, no failure in the present neutron dosimetry was experienced. On the other hand, the neutron flux in this experiment was converted to absorbed dose by the factor of 6.7×10^{-9} rad/n/cm², but a conversion factor of 6.05×10^{-9} rad/n/cm² has been used by foreign investigators (refer to Storer *et al*⁴⁾). If the latter factor were used in the present study, the RBE value for 14.1 MeV fast neutron would be about 10 per cent greater than the value described here.

SUMMARY

Adult *ddN* female mice were exposed to single whole-body radiation of 200 kVp X-ray, Co^{60} gamma-ray, and 14.1 MeV fast neutron.

From the probit regression lines on 30-day mortality of mice following exposure to each radiation, it was determined that the $LD_{50/30}$ was 640 rad for 200 kVp X-ray, 870 rad for Co^{60} gamma-ray, and 560 rad for 14.1 MeV fast neutron. When the RBE of X-ray is assumed to be 1.0, the RBE of gamma-ray is 0.7 and that of fast neutron is 1.1 for $LD_{50/30}$.

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* LET: Linear energy transfer

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